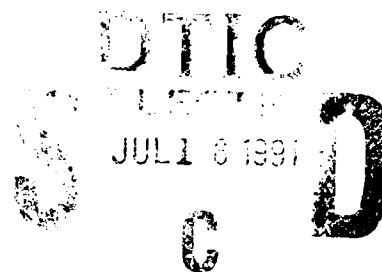


Marine Physical Laboratory

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TEST OF NEWTONIAN GRAVITY USING DSV SEA CLIFF

Final Report to
Office of Naval Research
Grant N00014-90-J-1063
For the Period 10-01-88 - 12-31-90
Principal Investigator(s): John A. Hildebrand and Mark A. Zumberge

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Scripps Institution of Oceanography
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Scientific Objectives

Several recent geophysical measurements have searched for deviations from Newton's inverse square law by testing for range dependence of the gravitational constant G . One group of these experiments observes the vertical gravity gradient above the earth using measurements on tall towers (Eckhardt *et al.* 1988; Thomas *et al.* 1989; Speake *et al.* 1990) and tests for deviations from Newtonian gravity but provides no direct estimate of G . Another group of geophysical experiments observes gravity from material slabs of known density by measuring within mines and boreholes (Stacey *et al.* 1987; Zumberge *et al.* 1990) or above fluctuating lakes (Moore *et al.* 1988; Muller *et al.* 1990) and yield estimates of $G(r)$. Collectively, these experiments offer little evidence for deviations from Newtonian gravity in the scale range 10 m to 1200 m.

Project Objectives

Our project was designed to measure the gravitational constant within the ocean using the submersible *Sea Cliff* over a scale length of 5000 m. A number of observables are needed to calculate the gravitational constant in an oceanic setting including: gravitational acceleration, depth, oceanic density, seafloor density, and seafloor topography. The strengths of our experiment are that gravity measurements were made over three-dimensions, that oceanic density was accurately characterized over three-dimensions, that seafloor density and topography were accurately mapped, and that the scale-length was large. This project was the first time a submersible was used as a platform for water-column gravity measurements.

Present Status and Progress During the Project Duration

Our experimental site was in the northeast Pacific ocean ($35^{\circ}13'N$ $132^{\circ}00'W$), approximately 600 km west of Monterey, California. This site was chosen to minimize gravity perturbations from the ocean-continent boundary, from oceanic fracture zones, and from oceanic currents and fronts. A 7000 km² area surrounding the site was mapped by multi-beam echo-sounding to characterize the topographic relief and seismic reflection profiling to measure the sediment thickness. Water density was measured with conductivity, temperature and depth (CTD) profiles, which determine density to better than 1 part in 10⁴ using the seawater equation of state.

We measured gravitational acceleration within the water-column using a Bell Aerospace BGM-3 gravity meter on a gyro-stabilized platform. The gravimeter sensor is a pendulous accelerometer, which has a high-gain servo loop to mechanically null a proofmass using a magnetic force. The sensor and associated electronics are housed in an oven to minimize thermal drift. The gravity sensor has a time constant of 4.5 seconds. A stabilized platform provides a vertical reference for the gravity sensor, using two gyro-stabilized feedback loops. It is capable of stabilization over an angular range of $\pm 30^{\circ}$ for pitch and $\pm 45^{\circ}$ for roll and maintains verticality to better than 1 milliradian.

The gravimeter was placed in the U. S. Navy submersible *Sea Cliff*, which is capable of descending to depths of 6100 m (20000 ft). A submersible pilot and an equipment operator accompanied the gravity meter to the seafloor on a total of four dives. The dives were, on average, 11 hours long and reached depths of more than 5000 m. At the beginning of each dive the submersible descended at a central position. At the seafloor, the submersible ballast was trimmed to be nearly neutrally buoyant, and gravity was read at a consistent location, allowing a check for instrumental drift. The submersible depth was monitored by two quartz pressure gauges (Paroscientific Model 410KT), which are accurate to better than one-meter when corrected for water density. The depth measurements at the central bottom site were repeatable to 0.2 m and the gravity measurements were repeatable to 200 μGal , with an instrumental drift of 100 $\mu\text{Gal/day}$. During three of the dives, the submersible was driven along the bottom approximately 1.5 km and an additional gravity reading was made before ascent to the surface. The resulting pattern of dive ascent locations is an equilateral triangle with a central point.

During the submersible deployments, gravity and depth were recorded every 12 seconds. To ascend, a series of weights were dropped giving the submersible positive buoyancy. We maintained the submersible at a uniform ascent rate, between 10 m/min and 25 m/min, however, weight drop events produced detectable vertical accelerations. To correct for vertical accelerations, we subtracted the second-derivative of the depth from the gravity data. These corrections substantially removed from the gravity the effect of weight drops. Figure 1 shows the gravity corrected for depth only, the corrections from the second-derivative of depth, and the corrected gravity for one of the four dives.

To account for the attraction of local terrain we used a digital representation of the multi-beam echo-sounding map. The terrain from a region 30 km by 30 km surrounding the dive sites was included at a 0.2 km grid spacing. The average seafloor density in this region is 2690 kg/m^3 , derived from the vertical gradient of an on-bottom gravity survey. We assumed the terrain to be uniformly 2690 kg/m^3 , and calculated its attraction using the average seafloor depth (5104 m) as a reference plane. The terrain attraction was calculated for locations along the dive ascents and is shown as a dashed line in the lower panel of Figure 1.

In Figure 1, the depth correction to the data accounts for the attraction of the sea water using the laboratory value of G . Because there is little or no residual slope in the corrected gravity profile, we see that the laboratory value of the gravitational constant does an excellent job of matching the observed vertical gravity gradient, especially for the oceanic slab that is more than one km above the bottom (where the terrain effect is negligible). This leads to a preliminary conclusion that the gravitational constant at scale lengths of one to four km equals the laboratory value. We expect that after completing the analyses of the other *Sea Cliff* dives, and incorporating these data with previously obtained observations with the submarine *Dolphin*, on-bottom gravity measurements, and sea-surface gravity surveys, this experiment will provide the best constraints on deviations from Newton's law to date.

Publications for FY90

Stevenson, J. M., Zumberge, M. A., and Hildebrand J. A., 1990. Deep-Ocean Gravity Measurements Aboard the Submersible *Seacliff*, *EoS*, 71, 1277.

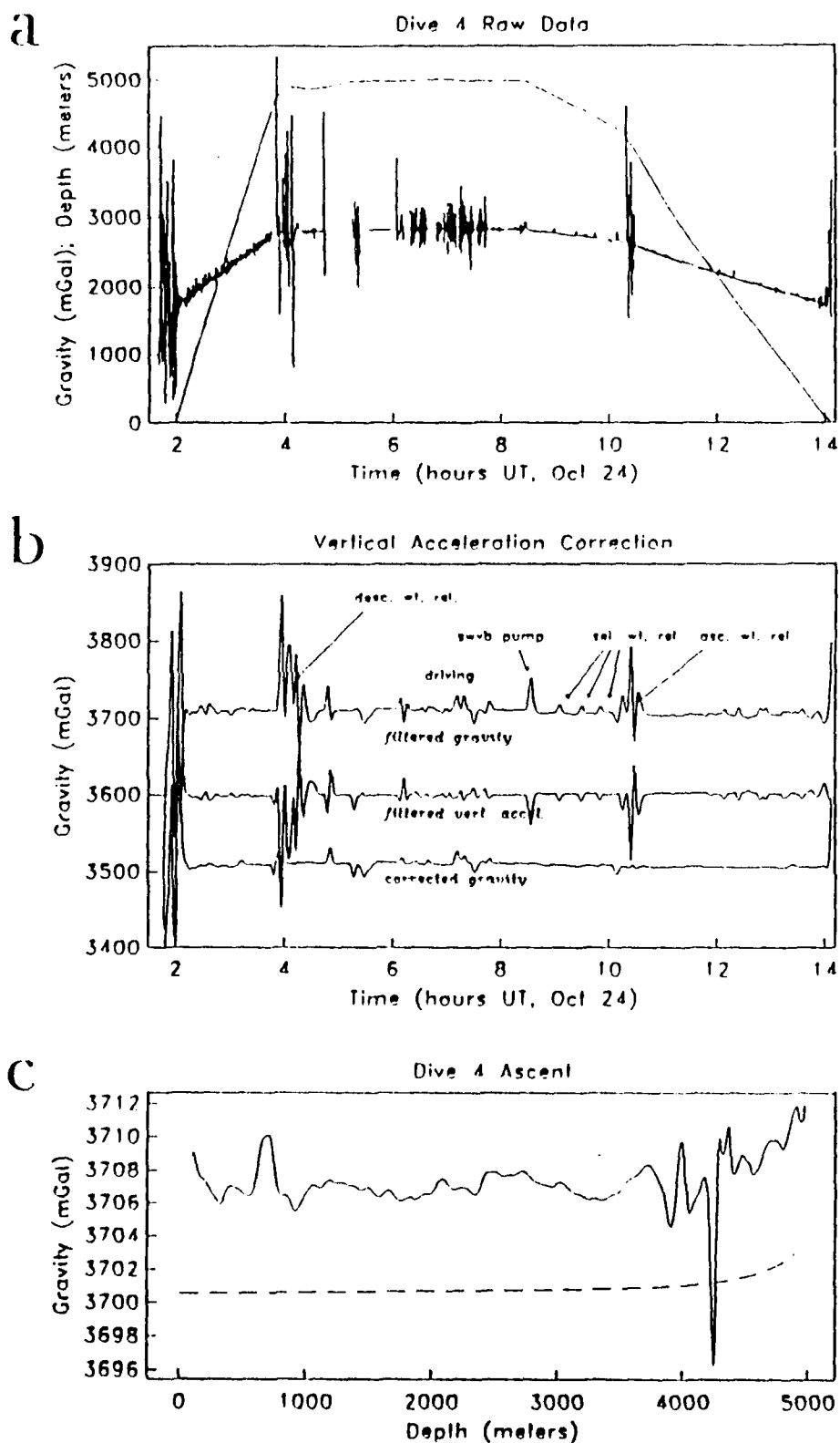


Figure 1. a) Raw gravity and depth data for a submersible dive. b) Gravity data corrected for depth using the laboratory value of $G = 6.672 \times 10^{-11}$ MKS (top), vertical acceleration correction from second differences of the pressure depth data (middle), and the sum of gravity and vertical acceleration data (bottom). c) Ascent gravity data as a function of depth (solid line) and terrain correction (dashed line).